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Abstract

LG Electronics developed an energy efficient resonant free piston linear compressor for a household refrigerator. This linear compressor has no crank mechanism and its piston is oscillated by linear motor and helical coil spring.
This compressor demonstrated excellent energy efficiency from the following reasons.

- Due to the simple mechanism, its mechanical loss is much less than conventional crank driven compressors
- Using the moving magnet type linear oscillating motor, its motor efficiency goes more than 90%
- With simple electronics, cooling capacity could be modulated to get better system efficiency

LG linear compressor is 20~30% more efficient than most efficient current crank driven compressors.

Introduction

The recent global awareness of the environmental protection raised great attention for energy saving of the household refrigerator and air conditioner. Up to this time, most of these appliances are powered by crank driven compressors which consume most of its electricity consumption.
Since conventional crank driven compressor had many difficulties to increase efficiency, new kind of compressors has been paid much of attention by the compressor manufacturers. The free piston compressor mechanism has been one of those kinds (Ref.1). This compressor had some advantages in tribological aspects over the conventional compressor since it does not produce any side load on the sliding bearing. So, this mechanisms has been widely used for oil-less compressor(Ref.2). Actually, this mechanism has been used for small refrigerator for more than thirty years (Ref.3).

LG Electronics utilized these free piston mechanisms to get better efficiency of compressor by reducing the friction loss and taking design freedom to get better flow path. Additionally, the stroke of the oscillating piston in the free piston linear compressor can be adjusted to modulate the compressor cooling capacity for better system COP (Ref.4,5). Only simple voltage adjusting electronic circuits are sufficient to do this.

But there were several key technologies which needed to be overcome in the linear compressor developments as follows,

- The design of highly efficient linear motor (Ref.6)
- The development of the spring with sufficiently small variation
- New means to supply lubricating oil
- The electronic controller to keep minimum clearance volume of the piston
- The advanced means to isolate noise and vibrations
- Last but not least, making whole above things cost effective and reliable enough in comparison with the conventional highly evolved crank driven compressor

Developments

Linear Motor

The linear motor can be classified according to the moving element as moving coil, moving iron and moving magnet type. By using some kinds of the moving magnet type linear oscillating motor, it was possible to get minimum side load with cost effective ways (Ref.6,7). To achieve minimum iron loss, the lamination of the linear motor is arranged in radial direction and the magnet wire is wound in ring shape which is easy for manufacturing (Ref.8,9).

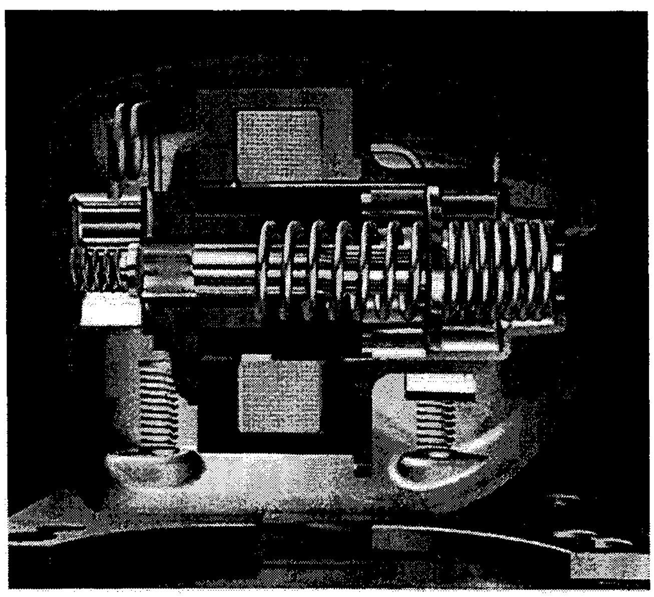

Fig.1 Linear Compressor Cross-section

Oil Pump

The major usage of the oil in compressor is to lubricate the sliding parts and to cool down the heat generated by compression, friction and motor loss. A simple free piston linear oil pump has been devised to pump up oil to lubricate piston and to cool down cylinder head. Since the oil pump was so efficient, pumped oil was not wasted. Therefore the total energy used for the oil pumping was very small and compression efficiency was increased a lot by efficient cylinder cooling (Ref.10,11)

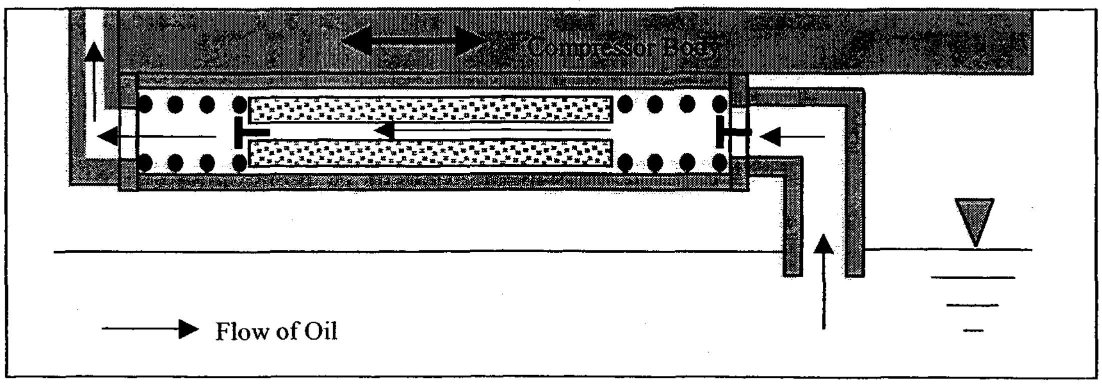

Fig.2 Schematic Diagram of Oil Pump

Valve System

To absorb small amount of the over-stroke of the piston, disk valve was used for the discharge. This kind of valve can minimize over-compression loss because it has much bigger flow area than conventional reed valves. Suction valve and suction flow path was placed on the piston to minimize flow resistance and suction heating loss. This kind of arrangement could be difficult in crank driven compressor because the crank mechanism itself will restrict to design optimum suction flow path (Ref.12,13,14).

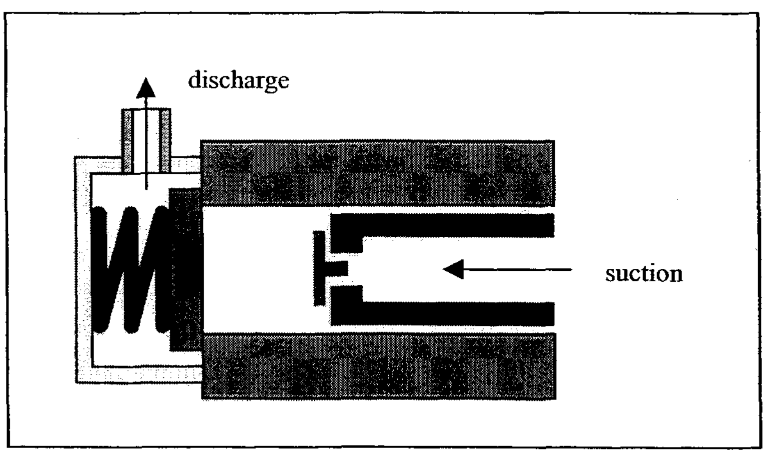

Fig.3 Suction and Discharge Valve System

Spring

Helical compression coil spring has been selected for the resonant spring because it is cost effective and very compact compared to other types of spring. But there were several careful considerations in design to keep minimum variation among compressors.

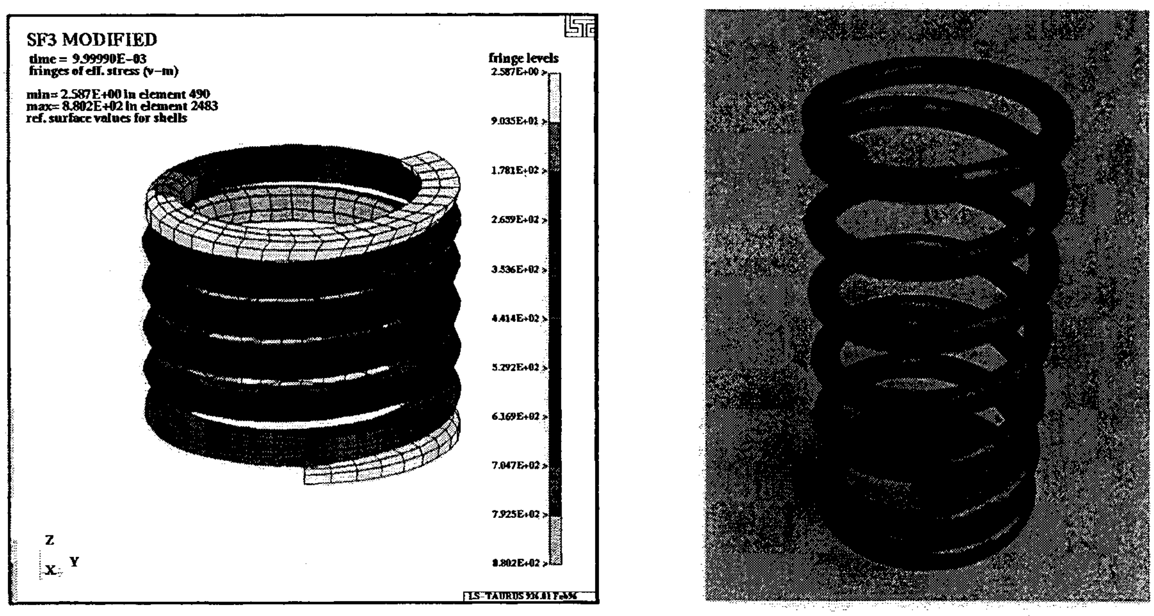

Fig.4 Spring of the Linear Compressor

Electronic Controller

The stroke of the piston was controlled by adjusting the mean voltage of the applied AC voltage using simple and inexpensive Triac based electronic circuit.

Manufacturing Technology

The Linear compressor needs several new manufacturing technologies like the assembly of the linear motor. But it has minimum parts to be machined accurately among whole existing compressors. So the machining was very easy in comparison with conventional compressors.

Performance

Compressor Efficiency

Moving magnet type linear motor used in LG linear compressor was more efficient than normal induction motor used for conventional reciprocating compressor, because it has no end-coil and rotor bar which caused lots of copper losses. Additionally, this efficiency can be kept nearly constant within normal load variation of the compressor (Ref.6).

Without using the crank mechanism, there is no journal bearing which usually takes about half of the friction loss in the crank driven compressor. Additionally, there is no crank bearing and connecting rod. Therefore the friction loss was minimized and tribological reliability was improved a lot in comparison with conventional one(Ref.15).

Using the valve system mentioned above, axial unidirectional refrigerant flow has been realized. This minimized the flow resistance and suction gas heating.

As a kind of the piston compressor, leakage loss in the linear compressor was negligible in comparison with the rotary or scroll type compressor.

With caring all above mentioned, LG linear compressor achieved superior efficiency. It has shown 20~30% more efficient than most efficient current reciprocating compressor. Its potential efficiency will be around 80% of the theoretical maximum efficiency even in this kind of small capacity compressor including the linear motor efficiency.

Capacity Modulation

Using the electronic controller, the stroke of the piston could be adjusted to modulate the swept volume of the piston. As discussed above, the efficiency of the linear motor remains almost constant with the variation of compressor load. But there is small amount of the increased re-expansion loss due to bigger clearance volume in reduced stroke. Actually it was easy to modulate compressor capacity without causing significant amount of loss between 50~100% of compressor capacity (Ref.4,5) which is sufficient enough in practical purpose

Noise and Vibration

The noise characteristics are basically the same as conventional reciprocating compressors. Major sources of noise are suction and discharge valves. But the Unidirectional valve arrangement gave us more design freedom for the noise reduction. (Ref.16)
Large moving mass including piston and magnet produces relatively large unidirectional vibration. However, it is relatively easy to isolate such vibration because of the unidirectional behavior of the vibrating motion. After re-designing the conventional suspension system, the vibration on shells was much smaller than the conventional reciprocating compressors.

Developed Linear Compressor

Fig.5 shows the linear compressor developed by LG electronics. Several parts are made of transparent plastic material for better observation.

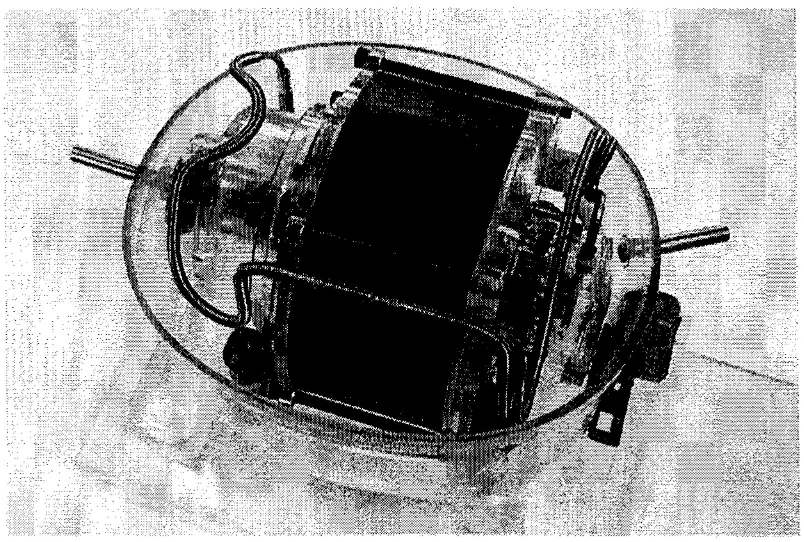

Fig.5 Linear Compressor for Refrigerator

Compressors." Purdue University, Ph.D., 1967, Engineering Mechanical.
18.D.E.B. Lilie, M. Krueger; "Friction Losses Measurements on a Reciprocating Compressor Mechanism" Proceedings International Compressor Engineering Conference, July 17-20, 1990, Purdue Unversity, West Lafayette, Indiana, USA
19.M.L. Todescat, F. Fagotti, A.T. Prata, R.T.S. Ferreira,"Thermal Energy Analysis in Reciprocating Hermetic Compressors", Proceedings International Compressor Engineering Conference, July 14-17, 1992, Purdue Unversity, West Lafayette, Indiana, USA
20.F. Fagotti, M.L. Todescat, R.T.S. Ferreira, A.T. Prata,"Heat Transfer Modeling in a Reciprocating Compressor", Proceedings International Compressor Engineering Conference, July 19-22, 1994, Purdue Unversity, West Lafayette, Indiana, USA

Refrigerator Performance with the Linear Compressor

According to experiments, the electricity consumption of a 680 ℓ top-mount refrigerator was reduced to 24% by drop-in replacement of the linear compressor. The reduction of 47% has been achieved with some additional modifications on the refrigerator. If the cooling capacity of linear compressor is modulated, the additional reduction of the electricity consumption will be achieved.

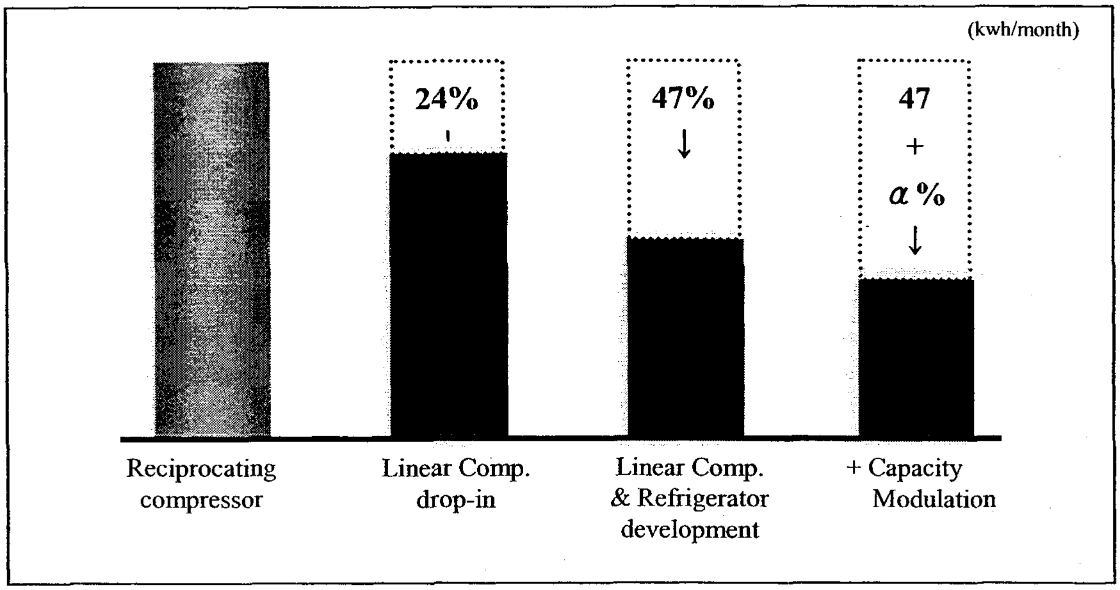

Fig.6 Electricity Consumption of a Refrigerator with Linear Compressor

Fig. 7 show the noise level of linear compressor on a on-off period in refrigerator operation. It can be easily understood from the figure that overall noise level of linear compressor was lower than reciprocating compressor. In addition, the soft start/stop operation of the linear compressor essentially eliminated sudden noise peaks existed in reciprocating compressor on/off.

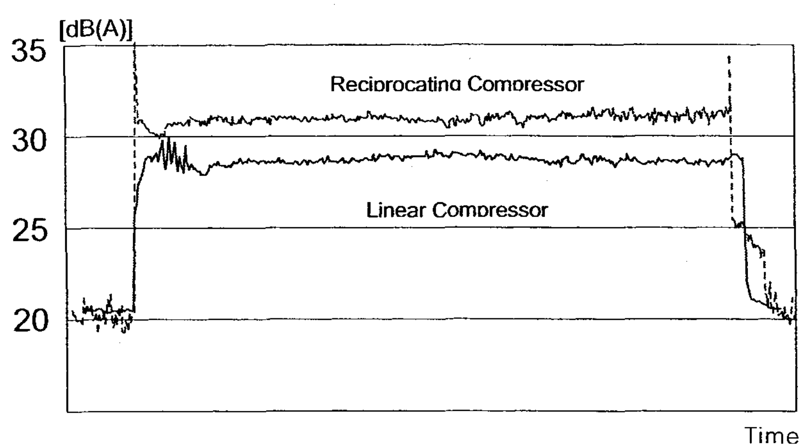

Fig.7 Noise Level for Refrigerator with Linear Compressor and Reciprocating Compressor

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References

1.Hirai, T. Koda, "Study on Oil Free Dual Resonant Piston Compressor." Proceedings International Compressor Engineering Conference, July 17-20, 1990, Purdue Unversity, West Lafayette, Indiana, USA
2.Reuven Z. Unger. "Linear Compressor for Clean and Specialty Gases", Proceedings International Compressor Engineering Conference, July 14-17, 1998, Purdue Unversity, West Lafayette, Indiana, USA
3.U.S. Patent 5,704,771. Issued 1-6-1998. "Vibrating Compressor."
4.Reuven Z. Unger, Nicholas R. van der Walt "Linear Compressor for Non-CFC Refrigeration." Proceedings International Appliance Technical Conference, May 13-15,1996, Purdue Unversity, West Lafayette, Indiana, USA
5.Reuven Unger. "Development and Testing of a Linear Compressor Sized for the European market" Proceedings International Appliance Technical Conference, May 10-12,1999, Purdue Unversity, West Lafayette, Indiana, USA
6.Redlich, R. "A Summary of Twenty Years Experience with Linear Motors and Alternators." Distributed at Linear Drives for Industry Applications, May 31 - June 2,1995, Nagasaki, Japan
7.U.S. Patent 4,602,174. Issued 7-22-1986. "Electromechanical Transducer Particularly Suitable for a Linear Alternator Driven a Free-Piston Stirling Engine "
8.U.S. Patent 5,945,748. Issued 8-31-1999. "Linear Motor Structure for Linear Compressor"Patented in Japan
9.U.S. Patent 5,751,075. Issued 5-12-1998. "Magnet Assembly for Linear Compressor " patented in Japan, Germany
10.U.S. Patent 5,993,175. Issued 11-30-1999. "Oil supply Apparatus for Friction Portion of Linear Compressor" Patented in Japan
11.U.S. Patent 6,024,544. Issued 2-15-2000. "Coolant Supply Apparatus for Linear Compressor" Patented in Japan
12.M. A. Di Flora, K. Wu, "Design and Performance of an "Inertia Reciprocating Compressor" Proceedings International Compressor Engineering Conference, July 14-17, 1992, Purdue Unversity, West Lafayette, Indiana, USA
13.U.S. Patent 5,947,708. Issued 9-7-1999. "Axial Flow Valve System for Linear Compressor" Patented in Japan
14.U.S. Patent 5,993,178. Issued 11-30-1999. "Linear Compressor" Patented in Japan.
15.W. Oh, H. Lee, I. Lee;"Measuring Friction Losses Using Accelerometer" Proceedings International Compressor Engineering Conference, July 19-22, 1994, Purdue Unversity, West Lafayette, Indiana, USA
16.U.S. Patent 5,722,817. Issued 3-3-1998. "Noise-Reducing Apparatus for Linear Compressor". Patented in Japan
17.CADMAN,Richard Vincent, "A Technique for the Design of Electro-dynamic Oscillating